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Seasonal Closures of No-Take Zones to promote A Sustainable Fishery for *Octopus Cyanea* (Gray) in South West Madagascar

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Recommended citation:
Humber, F, Harris, A, Raberinary, D. & Nadon, M. (2006). Seasonal closures of no-take zones to promote a sustainable fishery for *Octopus cyanea* (Gray) in Southwest Madagascar.

Abstract

The change from a subsistence to a cash-based octopus fishery in SW Madagascar has caused concerns over its long-term sustainability. Here, the results of the first two closures of an octopus No-Take Zone (NTZ) in the region, based on fisheries data collected between September 2003 and June 2006 are presented. The results show that the number and mean weight of octopus caught increased significantly after closure periods of the NTZ. However, the high intensity of fishing on the opening days reduced the potential longer-term benefits of the first NTZ closure, and a reduction in fishing pressure on the second opening lead to longer-lasting benefits.

This study demonstrates that seasonal, temporary closures of fishing sites are potentially a strong management tool in maintaining the sustainability of a traditional octopus fishery. The active participation and support of the local fishers was key to the success in the implementation and respect of the NTZ.

Table of Contents

List of Figures

Introduction

World Octopus Fisheries

The increasing international demand for marine products is a driving force fuelling the overexpansion of fisheries in many African countries (Cherif 2001; IEEP 1999; O'Riordan 2001). The decline in reef fish catches, and the low price paid for them, have encouraged fishermen to look towards invertebrate stocks as an alternative source of revenue (Cherif 2001; FAO 2004; Guard & Mgaya 2002; Perry, Walters & Boutillier 1999; Smith & Griffiths 2002). Octopus fisheries in southwest Madagascar have been the recent focus of a huge expansion, and finding a suitable management scheme to maintain their sustainability is imperative.

Octopus are ubiquitous across the world's oceans and support a global fishery that has grown significantly in recent decades (Cortez, González & Guerra 1999; Worms 1983). Between 1970 and 1980 the proportion of cephalopods in the total nominal catch of all fish and shellfish in marine and freshwater increased from 15.3% to 20.9% (Worms 1983). The most important commercial species include *Octopus vulgaris* (Cuvier), *Octopus maya* (Voss and Solis Ramirez), *Octopus tetricus* (Gould), *Octopus dolfleini* (Wülker), and *Octopus cyanea* (Gray) (Guard & Mgaya 2002; Rathjen & Voss 1987). Morocco leads the world in octopus exports, capturing as much as 44% of the global market in 2002 (FAO 2003, 2005); China, Spain, Senegal, and Mauritania are also large producers (FAO 2003, 2004, 2005). Import markets are mainly in Asia and Europe with Japan being the largest in the world and Italy being the largest in Europe (FAO 2004, 2005); in 2004, Japan imported 53,300 metric tons (MT) of octopus while Italy imported 44,000 MT. While the global market for octopus continues to grow, exports from the major producers have either levelled off or decreased in recent years as fisheries yields have diminished (FAO 2004, 2005; Hernández-García, Hernández-López & Castro 1998).

Many African nations now supply the large export markets to the European Union and Japan (Cherif 2001; FAO 2004, 2005; Guard & Mgaya 2002). However, data published by the FAO in early 2004 suggests that, while the global market for octopus continues to grow, many of Africa's octopus fisheries have peaked and are at the beginning of a decline. For example, the artisanal fishery of Mauritania exported 9,000 tonnes of octopus in 1993, but only 4,500 tonnes in 2001, despite twice as many active boats within the fishery (Cherif 2001).

Madagascar's Octopus Fisheries

Madagascar's fishing industry is relatively undeveloped compared to other countries in East Africa and the Western Indian Ocean region (FAO 2004; O'Riordan 2001; Rey 1982). The country has seen a rapid increase in fisheries production and export over the last twenty years with a doubling in the number of fishers in Madagascar (Billé & Mermet 2002a; Gabrié, Vasseur, Randriamiarana, Maharavo & Mara 2000). Traditionally, fishermen dried and traded octopus in regional inland markets but now foreign-owned seafood trading and collection companies purchase most of the catch, resulting in a change in recent years from a barter and subsistence economy to a market-driven cash based economy (Langley 2006). The change to an international market for octopus has increased both the value of octopus and the quantity harvested. Madagascar represents one of the few African nations that is still increasing its octopus fishery output, and between 2002 and 2003 there was a 35% increase in octopus exports to France (FAO 2003, 2004, 2005).

The traditional artisanal fishery for *O. cyanea* in southwest Madagascar is an important economic activity. Octopus represents approximately 11.8% by wet weight of marine resources captured on the reef flat of the Grand Recif of Toliara. This represents 18.9 tons/km^2/year, which is greater than the finfish catch from pirogues (canoes, made by hollowing out a large log) (Gabrié *et al.* 2000). However, in the southwest there is already evidence of over fishing, (Iida 2005; Laroche, Razanoelisoa, Fauroux & Rabenevanana 1997; McVean, Hemery, Walker, Ralisaona & Fanning 2005; Woods-Ballard, Chiaroni & Fanning 2003), and national research organisations have raised concerns over fishing pressure.

Andavadoaka's Octopus Fishery

This study is centred on the village of Andavadoaka, south west Madagascar, in a region where octopus represents over 70% of the marine produce bought by the fishing collection companies, the primary income provider in the region (Copefrito, pers. comm.). The 1200 inhabitants of this traditional artisanal fishing community belong to the Vezo ethnic group, a seafaring people indigenous to the south west of

Madagascar, whose identity and way of life is heavily dependent on the sea. Anecdotal evidence gathered during discussions with Vezo fishers in Andavadoaka in 2003 suggested that the arrival of export markets in 2003 considerably increased the fishing pressure for octopus, and that the yield from the octopus fishery in the Andavadoaka region in the southwest has fallen in recent years (Langley 2006). A comparison in the number of octopus seen per scuba dive in Andavadoaka and the unfished reefs of the Chagos Archipelago, in the central Indian Ocean, also revealed a marked difference in the frequency of observations of *O. cyanea*. In the Andavadoaka region is estimated that approximately one octopus was seen underwater per 200 dives, whereas in Chagos it was estimated that between six to eight octopus were seen each dive (Harris, A. pers. comm.)

Marine reserves and no-take zones (NTZs) are popular tools in fisheries management and their success in increasing density and biomass of stocks has been well documented (Halpern 2003; Pipitone, Badalamenti, D'Anna & Patti 2000; Polunin & Roberts 1993; Roberts, Bohnsack, Gell, Hawkins & Goodridge 2001; Roberts, Hawkins & Gell 2005; Rodwell & Roberts 2004). Management of cephalopod fisheries has often been based on effort control (Basson, Beddington, Crombie, Holden, Purchase & Tingley 1996; FAO 2005) and whilst the rapid growth and short life span of octopus (Guard & Mgaya 2002; Semmens, Pect, Villanueva, Jouffre, Sobrino, Wood & Rigby 2004; Van Heukelem 1973) makes them vulnerable to population crashes, it also permits octopus stocks to recover quickly under favourable conditions. Therefore, applying suitable management controls to the fishery could rapidly reverse a decline in stock.

In September 2003 an octopus NTZ was created that would be closed to octopus fishing for selected periods of the year (see 'Implementation of the NTZ'), to establish whether NTZs were a viable management tool in maintaining the future sustainability of the octopus fishery in the Andavadoaka region. In this paper we present the results of the first two closures of the NTZ in Andavadoaka, south west Madagascar, between November 2004 and June 2006. The aim of this study was to assess the effects of the closures on the abundance, mean weight and catch per unit effort (CPUE) of octopus from the NTZ. The results of the NTZ were evaluated using fisheries data collected from the region before, during and after the closure periods of the NTZ, and we discuss the feasibility and suitability of this management technique as a tool to develop a sustainable octopus fishery elsewhere in the region and beyond.

Biology of *Octopus cyanea*

Octopus cyanea, the primary species caught in the Andavadoaka region, is a cryptic species most active as an opportunistic predator feeding on molluscs and crustaceans (Wells and Wells 1970, Mangold 1983, Van Heukelem 1983, Norman 1991, Forsythe and Hanlon 1997). During the daytime *O. cyanea* occupies holes and crevices found in coral reefs, seagrass beds, and across rocky, sandy or muddy bottoms ((Mangold 1983, Van Heukelem 1983). Activity of *Octopus cyanea* is greatest early in the morning and late in the afternoon, and one study approximated that the species spends 24-35% of the daytime out of their dens actively foraging, and no time foraging throughout the night (Forsythe and Hanlon 1997). At night and at midday, the octopus are usually withdrawn deeply into their dens, with rubble or shells pulled over the opening. However, in very shallow to intertidal habitats such as the Great Barrier Reef, *0. cyanea* foraging may be regulated more by tide (Forsythe and Hanlon 1997).

It is thought to be the most common octopus on reefs (Van Heukelem 1983, Roper and Hochberg 1988) and occurs from the water surface to a depth of at least 150 m across tropical and temperate coastal waters and continental shelves. The lifecycle of *O. cyanea* is characterized by an exponential growth (Van Heukelem 1973, Semmens et al. 2004) and a short life span (12 to 18 months after settlement)(Van Heukelem 1973, Boyle 1990). It can reach sizes of 5 – 6 kg and greater during this time (Van Heukelem 1973, Mangold 1983, Van Heukelem 1983, Domain et al. 2000).

Cephalopods are dioecious and fertilisation is normally achieved through direct mating. Females die shortly after the eggs hatch and males die a few months after maximum enlargement of specialised suckers (Van Heukelem 1973). Males may reproduce with multiple partners while females die after brooding a single clutch of eggs, which may take up to 4 or 5 months to hatch and contain up to 700 000 eggs (Mangold 1983, Van Heukelem 1983), and the number of eggs a female produces is proportional to the size of the female octopus (Oosthuizen and Smale 2003). Hatched larvae have a 4 to 8 week pelagic stage before settling to on

the bottom (Itami et al. 1963, Villanueva 1995). Daily growth rate is estimated to be 1.93% at 1000g and 1.34% at 5000g, and sexual maturity can be attained at a wide range of body sizes within the species (Boyle 1990). Studies on *O. cyanea* and *O. vulgaris* have found that water temperature, light, age, diet, and feeding rate can influence growth and maturation (Mangold 1983, Van Heukelem 1983, Domain et al. 2000). Male *O. cyanea* are thought to mature at approximately 320g whereas females mature at approximately 600g (Guard and Mgaya 2002) although there is great variability among individuals (Smale and Buchan 1981, Boyle and Boletzky 1996, Guard and Mgaya 2002, Silva et al. 2002, Semmens et al. 2004) which means that any individual less than 500g is unlikely to have had the chance to reproduce.

A study in Tanzania by Guard and Mgaya (2002) using gonadosomatic indexes and recruitment observations showed that the peak brooding period for *O. cyanea* was June and, to a lesser extent, December. These peaks were followed by . recruitment events about 3 months later in September and February, respectively. In southwest Madagascar, unpublished data by J. Laroche suggests a peak brooding period in November-January followed by a recruitment event 5 months later in April-July. A smaller brooding period is also noted in July-August with a related smaller recruitment event in December-January.

While there are few records of significant horizontal movement by populations and closely situated population appear to be genetically distinct (Mangold 1983, Van Heukelem 1983), seasonal vertical migrations of animals amongst habitats associated with water temperature and reproduction have been reported (Smale and Buchan 1981, Mangold 1983, Van Heukelem 1983, Anderson 1997, Oosthuizen and Smale 2003). *O.cyanea* dens are not permanent, although there are records showing individuals to occupy the same den for up to 35 days (Mangold 1983, Van Heukelem 1983, Forsythe and Hanlon 1997)

Materials and Methods

Study Site

The study is centred in the region surrounding the village of Andavadoaka, located approximately 150 km north of Toliara and 50 km south of Morombe in southwest Madagascar (Fig. 1). The Andavadoaka region is characterized by two large reef systems: fringing reefs and barrier reefs (Gabrié *et al.* 2000; Iida 2005; Nadon, Griffiths, Doherty & Harris 2005) and important octopus fishing sites are located on both systems. Octopus are harvested by the Vezo fishing community of the region through reef gleaning (Iida 2005). The reef flats in the region of Andavadoaka are accessible by foot for only 3 – 7 successive days during spring tides (approximately every 9-13 days). At low spring tides, women and children scour exposed reef flats for octopus with long, sharp sticks. Men also take part in reef gleaning but will also free dive with spears over shallow reef edges (<5m) for octopus.

The reef flat is searched for octopus dens and any potential dens, which are recognizable by the coral rubble placed by the octopus to cover the entrance, are explored with the sharpened stick. If an octopus is occupying the den they grab onto the stick and are immediately pulled out by the fisher and killed. Reef gleaning is unselective because small sized octopus can not be rejected before the den is explored and are likely to be injured in the hunting process and will not be returned by the fisher once they have been pulled out. In southwest Madagascar, fishers can immediately sell their catches to villagers that serve as local collectors, known as 'sous-collectors', for fisheries companies. Since 2003, two principal marine fisheries companies, Copefrito and Murex, have purchased fish, octopus, squid, crab and lobster from sous-collectors in the Andavadoaka region between Antsepoka and Antsatramoroy.

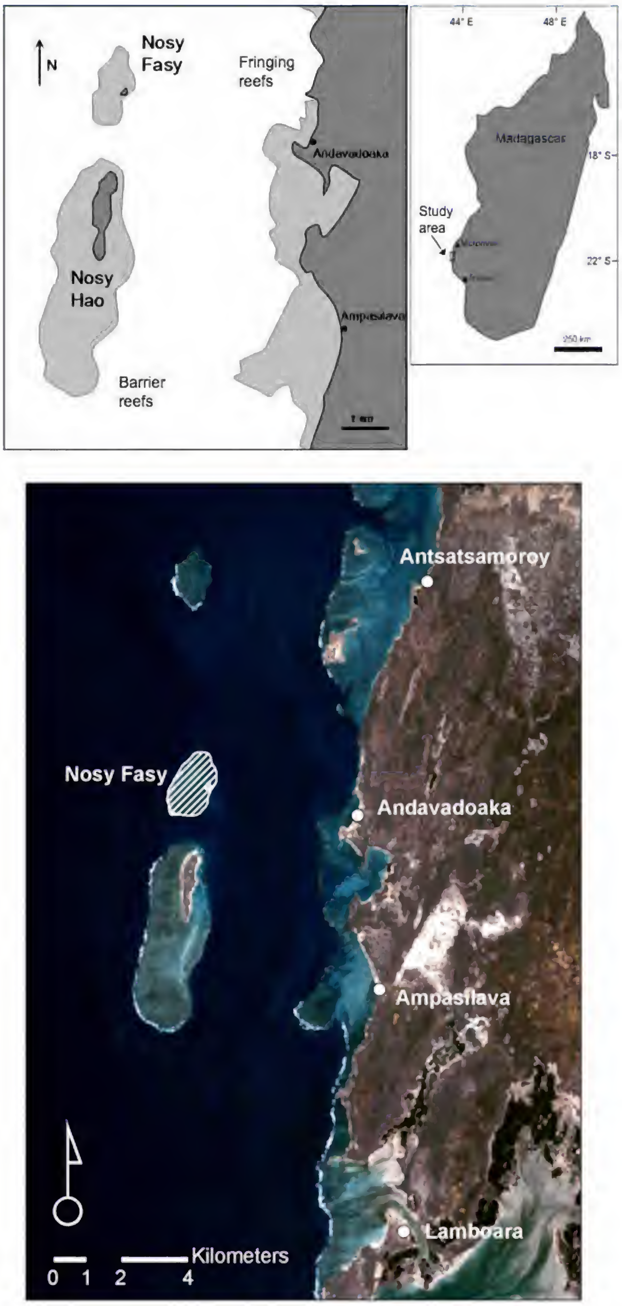


Figure 1: Map showing the location of Blue Ventures study site in South West Madagascar, and a satellite image showing the location and area of the Nosy Fasy NTZ (200ha) in the Andavadoaka region.

Implementation of the NTZ

In September 2003 meetings between Blue Ventures Conservation (BV), the Wildlife Conservation Society (WCS) and both female and male fishers were held in Andavadoaka and it was agreed that an octopus no-take zone should be created with the following aims:

- Maintain sustainable yields of octopus
- Increase the size of octopus caught
- Increase the price paid to fisherman for octopus
- Integrate resource monitoring into the collection process

The 200ha reef flat surrounding the sand cay of Nosy Fasy, a barrier island located 5km offshore adjacent to the village of Andavadoaka, was chosen as the site of the octopus NTZ (Fig. 1). A *Dina*, or local law, was also created to officially protect the site from octopus fishing during the planned closure period, although fishing for other species could continue. As a barrier island located in front of the village, the Nosy Fasy NTZ could be clearly delimited. A guardian was also hired to prevent poaching. The first closure of the Nosy Fasy NTZ was for a 7 month period between the 1st November 2004 and the 5th June 2005. The chosen length of closure was experimental, since there had been no previous NTZs in the region, and the fishers decided that the NTZ was to open at the start of the first spring tide in June 2005. The second closure was for a 4.5 month period between the 15th December 2005 and the 28th April 2006. The 15th December was also the start of new fisheries legislation, which brought about Madagascar's first regional closure to octopus fishing, between the 15th December 2005 and the 31st January 2006. The length of closure was a compromise reached between the fishers recognising the various differences in opinion amongst community members on the second closure length.

Data Collection

Between September 2004 and September 2005 all sous-collectors operating in 10 villages in the Andavadoaka region were employed by BV to collect data on the octopus sold to them. From October 2005 onwards the number of sous-collectors hired was reduced to a sample from each village in the area. All collectors were visited regularly during spring tide periods by the field research coordinator to ensure proper data collection. The sous-collectors recorded the following information on each octopus:

Individual wet weight

Site caught

Fishing method

Number of fishermen in the fishing group

Fisherman name, sex and age

Furthermore, the datasets from different collectors were inspected and compared to one another for signs of improper or inaccurate data collection. Due to the highly cryptic nature of octopus, no attempts were made to record direct field measurements of octopus size or abundance.

Furthermore, no data was collected from the NTZ during the closure periods, as this would have involved breaking the "*Dina*" in order to collect and kill octopus, and may have caused tension between the scientists and the villagers.

Data Analysis

All data was analysed using Excel and Minitab to provide results for catch yields, average weight by month, catch per unit effort (CPUE) and weight frequencies. CPUE was standardised as monthly mean wet weight of octopus/person-day, so that the NTZs and control sites could be compared, as individual fishing sites can have a different number of days fishing during spring tides depending on their location, and a variable number of "fishable" spring tides in a month.

To compare changes in mean weight over time between the NTZs and fished sites, data from 4 control sites were combined. Underwood (1992) suggests the use of multiple control sites as an improved method to distinguish the effects of an impact from those of background environmental variation. The 4 control sites were chosen at random from a set of octopus fishing sites that experienced constant fishing pressure over the study period.

The percentage change in the count and sum weight of octopus was plotted so that the two closure periods could be compared. An increase in both count and sum weight after each closure period was expected if the NTZ closure had successfully increased the recruitment and size of octopus. To account for the change in sampling method (a reduction post-September 2005 to only one sous-collector per village compared to all sous-collectors being hired in each village pre-September 2005) the percentage change after the first closure was calculated against data from September and October 2004, whilst the percentage change after the second closure was calculated against data from

October to December 2005. The absolute values for count of octopus and sum weight over time were also plotted so that the pattern of change over time was more clearly visible.

The mean weight and CPUE of octopus by month at the NTZs were analysed for significant differences before and after each closure period, and against the control data using 1-way ANOVA and a Bonferroni *post hoc* test, as a significant increase in weight and CPUE after each closure period and compared to the control would indicate that closing the NTZ had led to a significant increase in octopus recruitment and size.

To show in more detail the shift in weight distribution in the octopus population from the NTZ, the weight frequency distribution for before the first closure and post each closure was plotted for the NTZ and for the same period at the control sites. The weights in each period were tested for any significant differences between each other using 1-way ANOVA. We would expect the NTZ to show a shift in weight distribution whilst the control site would show no shift in weight distribution.

Results from Nosy Fasy NTZ

Total Octopus Catch

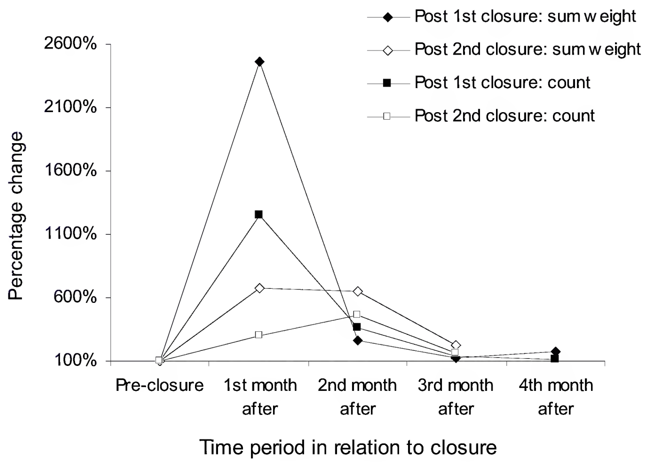
The data analysed represents 2856 octopuses caught at the Nosy Fasy NTZ between September 2004 and June 2006. Before the first closure of the NTZ, octopus from Nosy Fasy comprised 4% of regional octopus catch by count rising to 9% after the first closure period and 14% after the second closure period. For the Vezo people of Andavadoaka, who account for 89% of fishing activity at Nosy Fasy, octopus catch at Nosy Fasy increased from 14.0% of the village's total octopus catch before the closures to 25.8% after the first closure and 47.2% after the second closure.

The percentage changes in the number and total weight of octopus taken from the Nosy Fasy reef flat after each closure period (Fig. 2) show an increase, and that there was a greater increase in octopus catch (both number of individuals and total weight) after the first closure compared to the second closure. The number of octopus caught in June 2005, after the first closure period, increased by a factor of thirteen to 1126, compared to the pre-closure level of an average of 84 per month (Fig.3). Although there was a significant drop in the number taken in subsequent months the number of octopus caught still remained over double the pre-closure figure. A mean sum weight of 48kg of octopus per month was taken from Nosy Fasy before the first closure period. After the first closure this increased 25-fold. Although total biomass dropped significantly after June 2005 it remained over 100kg/month for July to September 2005. The changes in post-closure catch are further examined in the next section.

From October 2005 the recording effort was reduced so that the number of octopus recorded each month represented a sample of the total catch.

The second closure period had similar, though perhaps less spectacular, effects on post-closure octopus catch to the first. The number of octopus caught in April 2006 more than quadrupled compared to December 2005. The number of octopus caught increased further in May 2006 and although there was a decrease in June 2006, catch numbers still remain greater than pre-closure levels. Despite there being only three days of fishing in April 2006, after the second closure period the total biomass sampled from Nosy Fasy had increased 7-fold compared to pre-closure levels which continued to May 2006.

Figure 2: The percentage change in the number and sum weight of octopus caught from Nosy Fasy NTZ after each closure period. The change has been calculated as an increase from each pre-closure level taken as 100%.

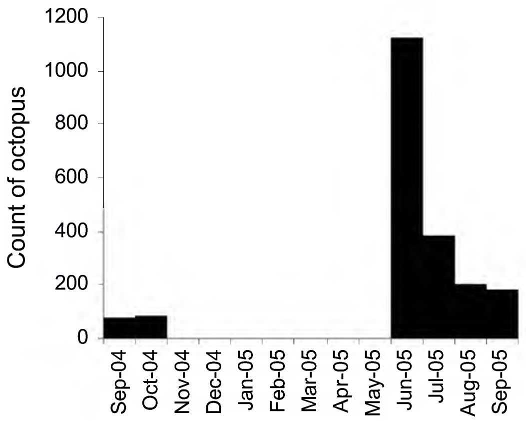


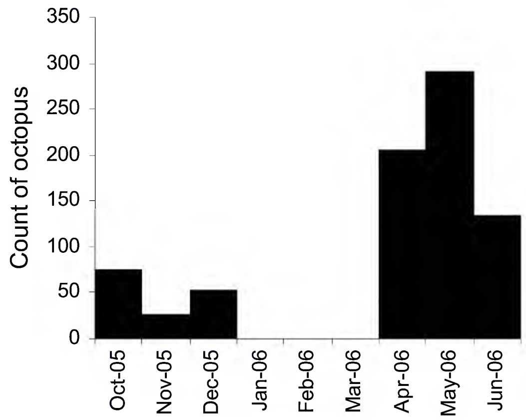
Mean Weight

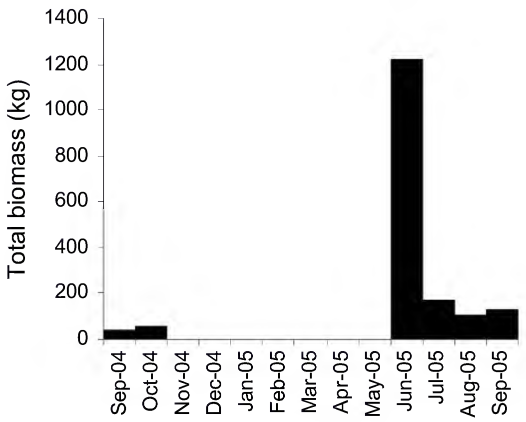
The 1-way ANOVA showed that there were significant increases in the mean weight of octopuses caught at Nosy Fasy after each closure period in comparison to the mean weight in the month preceding each closure ($p<0.001$) (Fig. 4). The mean weight doubled from a pre-closure level of 569g to 1086g after the first closure of the NTZ in June 2005. The mean weight at Nosy Fasy in June 2005 was significantly greater than that of the control sites ($p<0.001$). The effects of the NTZ were reduced by July 2005 and mean octopus weight returned to pre-closure levels, and below that of the (continuously fished) control sites.

Figure 5 shows that there was a reduction in mean weight of octopus by 650g (54%) after the first day of fishing after the NTZ had reopened in June 2005.

Figure 3: Changes over time in the number of octopus caught and the total biomass from Nosy Fasy NTZ. Note the data has been divided into two periods to account for the change in sampling after September 2005. There is no data for the periods when the NTZ was closed.







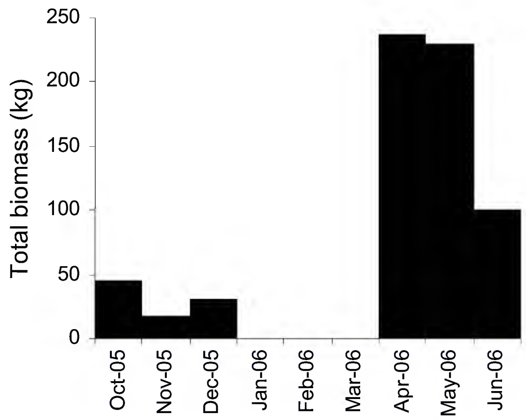
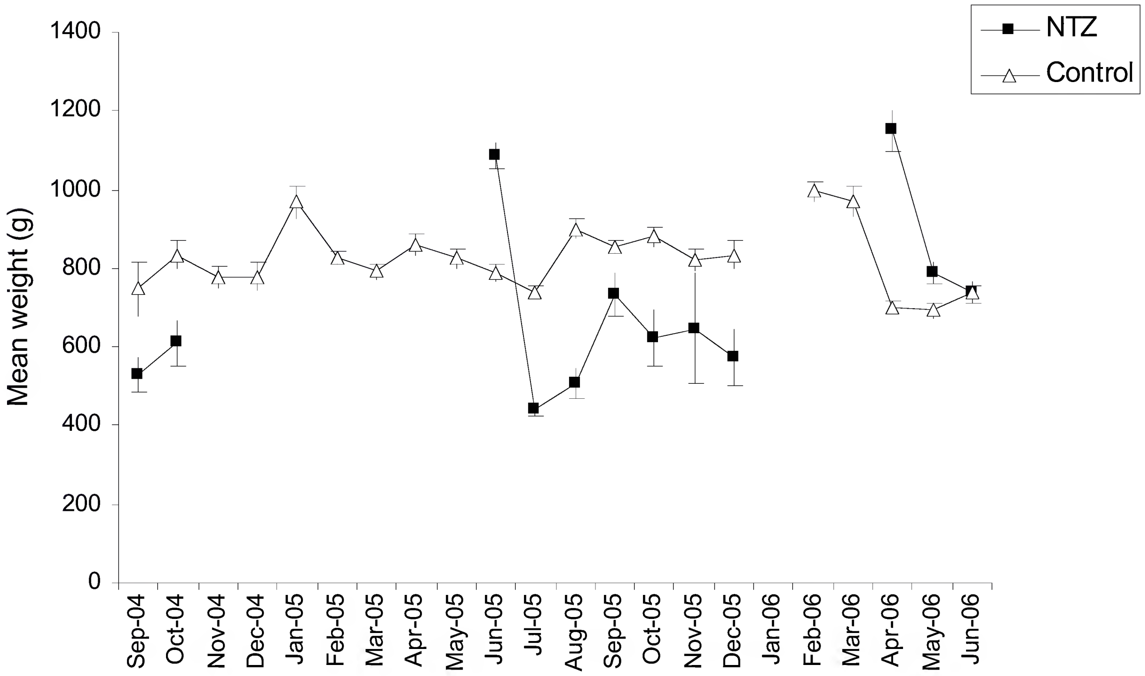
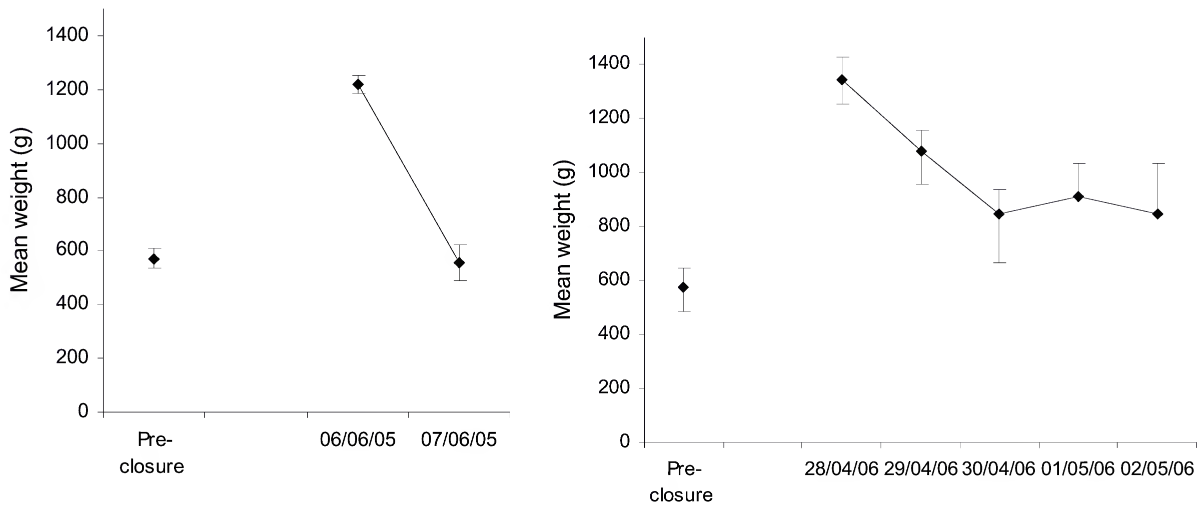


Figure 4: Changes in mean weight (±SE) of octopus from Nosy Fasy over time compared to the mean weight of 4 control sites. (* indicates a significant difference between pre- and post- closure mean weights from the NTZ and between the NTZ and control, p<0.001). Note there are no data fro the periods when the Nosy Fasy NTZ was closed and during the national closure to octopus fishing (15th December 2005 to 31st January 2006)**



After the second closure period the mean weight doubled from the pre-closure weight of 575g in December 2005 to 1150g, and there was a significant difference in the mean weights of octopus from Nosy Fasy and the control sites in April 2006 ($p<0.001$). The mean weight of octopus from Nosy Fasy has remained above the mean weight of the control sites after the second closure period, and shows that the mean weight only decreased by 365g (19%) after the first day of fishing of the second closure (Fig. 5).

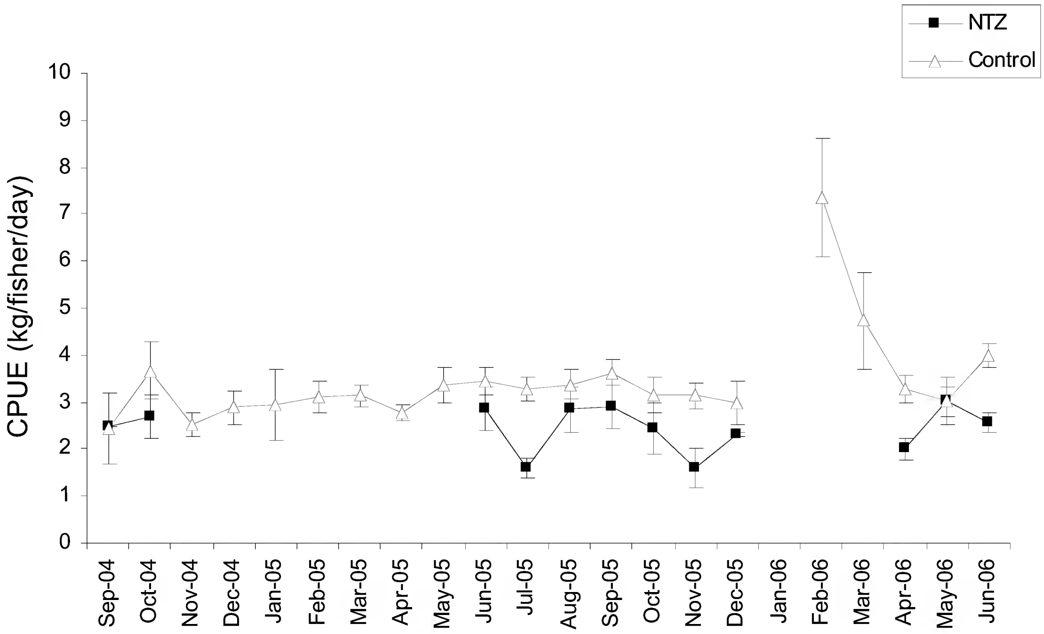
Figure 5: The mean weight (±SE) of octopus caught at Nosy Fasy NTZ on the first day of the opening spring tide and the rest of the spring the after each closure period. (* indicates a significant difference between pre- and post-closure mean weight per day p<0.001)**



Catch per Unit Effort (CPUE)

The 1-way ANOVA showed that there were no significant differences between CPUE before and after closure periods at Nosy Fasy (Fig.6). However, there was a significant increase in CPUE on the first day immediately after the re-opening of the Nosy Fasy NTZ in June 2005 (Fig. 7). The CPUE on the opening day after the first closure period (6th June 2005) was 8.7kg/fisher/day, whilst the CPUE for the rest of the opening spring tide was reduced to 2.0kg/fisher/day resulting in the observed average of 2.7kg/fisher/day for June 2005, compared to the pre-closure average of 2.6kg/fisher/day. There was no significant increase in fishing pressure on the first day after the second opening of the NTZ on April 28th 2006, and CPUE remained similar to the closure level. It is important to note here that the large increase in the control CPUE in February 2006 was the result of the end of the first national closure to octopus fishing in SW Madagascar from the 15th December to the 31st January. The national closure is likely to have had a greater effect on CPUE than the NTZ because there would have been a greater fishing effort spread over all the possible octopus fishing grounds, thus reducing the impact on any one site and allowing all fishers to fish to a maximum effort.

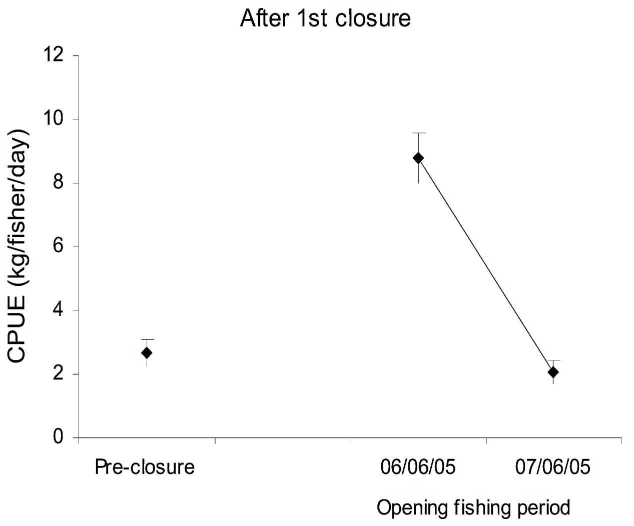
Figure 6: Changes in CPUE (monthly mean wet weight of octopus.person-day) from Nosy Fasy NTZ over time (±SE). Note there are no data fro periods when the Nosy Fasy NTZ was closed and during national closure to octopus fishing (15th December 2005 to 31st January 2006). There were no significant differences between the CPUE from the NTZ and the control during any month.



Weight frequency distribution

Examining the weight frequencies of octopuses from Nosy Fasy before and after the two closure periods (Fig.8) it is clear that there has been a significant shift in the weight frequency distribution towards higher weights after each of the openings of the NTZ ($P<0.001$). Before the first closure of the NTZ an average of 41% of octopus were over 500g, which increased to 73% after the second closure of the NTZ. The number of octopus over 1500g also tripled from 4% before the first closure to 13% after the second closure. Although the control sites also appear to have a greater frequency of larger octopus between April to June 2006 (Fig. 9), the differences in mean weight were not statistically different.

Figure 7: The mean CPUE (±SE) of octopus weight at Nosy Fasy NTZ on the first day of the opening spring tide and the rest of the spring tide after each closure period. (* indicates a significant difference between pre- and post- closure mean weight per day p<0.001).**



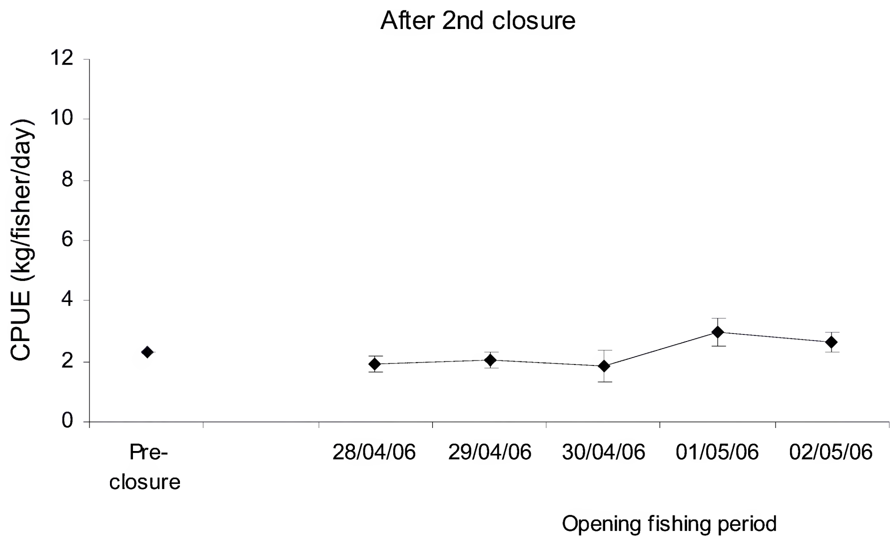


Figure 8: Weight frequency distribution of octopus before the closure of Nosy Fasy NTZ after the first closure of the NTZ and after the second closure of Nosy Fasy NTZ. White= before closure (Sept-Oct 2004); Grey= after the first closure (June-Dec 2005); Black- after the second closure (Apr-June 2006)

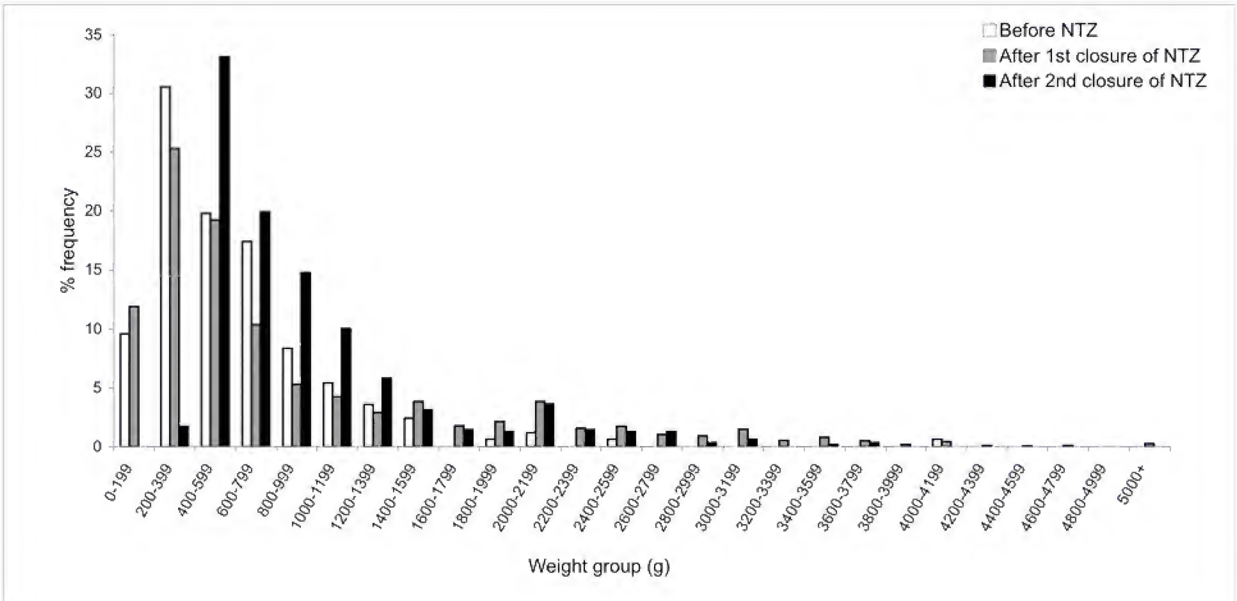
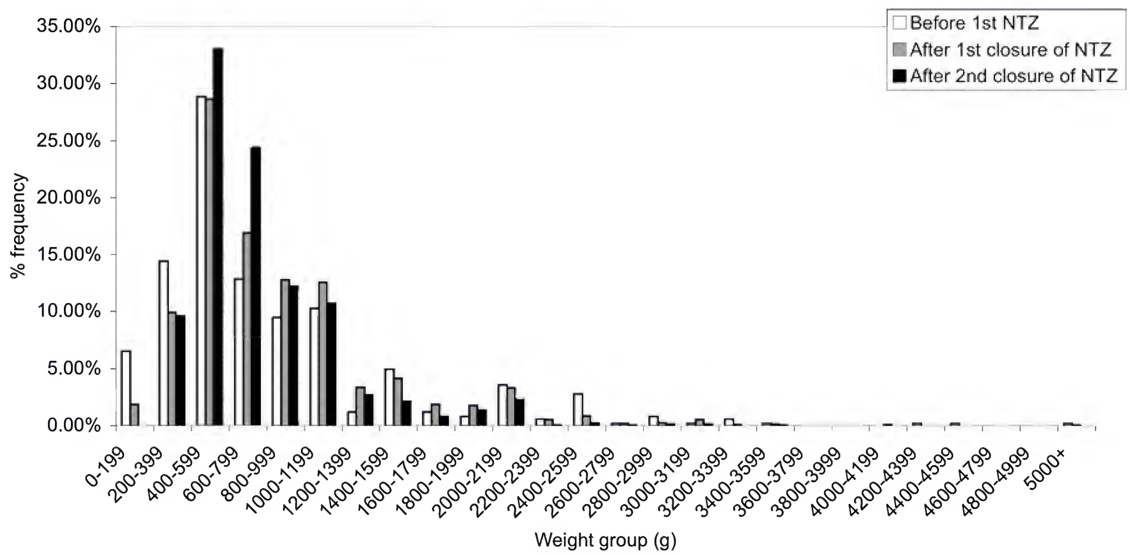


Figure 9: Weight frequency distribution of octopus at the control sites during the same three opening periods at Nosy Fasy. White= before closure (Sept-Oct 2004); Grey= after the first closure (June-Dec 2005); Black- after the second closure (Apr-June 2006)



Discussion

Analysis of the results

The results of Nosy Fasy NTZ show that octopus abundance and weight increased rapidly during the closure periods. Although an increase in the octopus population is inferred from an increase in the number caught, it is unlikely that this observation is simply a consequence of an increase in the number of fishers, since once normal fishing levels resumed after the opening days, more octopus were still caught in comparison to pre-closure levels. The increase in weight is more clearly shown as a significant shift in size distribution after both closure periods, with a 32% rise of octopus caught over 500g between September 2004 and June 2006 and a 9% rise of octopus caught over 1500g. At present, fishermen are paid a set price per kg for octopus depending on whether they are greater or less than 1500g. A minimum size of 500g for octopus was implemented by the fisheries export company, Copefrito, as similar limits have been placed in western Africa to prevent the marketing of undersized octopus (FAO 2005), but was not enforced as fishers were unable to distinguish size of octopus before catching them and were unlikely to return them to the water once speared.

Increases in the abundance of octopus are likely to have been a result of the protection of brooding females (Oosthuizen & Smale 2003) and an increase in the reproductive output of the females, which only brood once in their lifetime, normally at their largest size (Boyle 1990). Therefore increasing the average size of the population should increase its reproductive output. Male *O. cyanea* (G.) mature at approximately 320g whereas females mature at approximately 600g (Guard and Mgaya 2002), and although there is great intra-species variation (Aliou 1989; Boyle & Boletzky 1996; Domain, Jouffre & Caveriviere 2000; Guard & Mgaya 2002; Hatanaka 1979; Iribarne 1991; Semmens *et al.* 2004; Silva, Gil & Sobrino 2002; Smale & Buchan 1981), it is likely that any individual caught smaller than this is unlikely to have reproduced. Protecting reef flat areas may also be beneficial as it is thought that they are used by immature female octopus to feed and grow before migrating to deeper areas to spawn (Oosthuizen & Smale 2003). Therefore, leaving reef flats unfished for several months before peak spawning could considerably enrich spawning production and potentially recruitment.

The positive effects of the first closure of the NTZ were short-lived and a month after the first opening the abundance and mean weight of octopus returned close to pre-closure levels and mean weight was less than that of the controls. After the second closure octopus abundance and mean weight did not fall so rapidly and mean weight has remained above the control weight for the 2 subsequent months. Differences in the length of benefits after the NTZ opened are most likely to be due to the differences in fishing pressure the NTZ experienced during the very first opening fishing period following each reopening. CPUE per month does not increase after the first closure despite there being an increase in the number and mean weight of octopus. This was a product of grouping data into months which masked the effect of the overfishing on the opening day of the 6th June 2005. CPUE on the 6th June was 8.7 kg/person, a significant increase compared to the pre-closure CPUE. From observations during the reopenings it is estimated that over 1000 fishers visited Nosy Fasy on the 6th June 2005. This number is approximately equivalent to the numbers that would have normally visited Nosy Fasy over a period of 4 months. The high intensity of fishing on the opening day was responsible for significantly lowering the abundance and weight of octopus for the rest of June 2005.

The fishers were keen for the intense overfishing to not reoccur on the second opening and to restrict the number of 'freeriders': those that did not fish at Nosy Fasy on a regular basis and had not invested in the Nosy Fasy but came to fish on the opening day as a result of high expectations, in villages throughout the region,

of abundant fishing yields after the first reserve was reopened. There was a marked reduction in the fishing intensity on the opening day of the 28th April 2006 after the second closure as a result of a number of factors. Less favourable fishing conditions and the simultaneous opening of two separate NTZs at different locations in the Andavadoaka region meant that approximately 250 fishers came to Nosy Fasy, and although 'freeriders' were not evicted or chased away by local fishers they were informed that if they wanted to glean for octopus then they should contribute to the payment of the guardian in the future. Despite a marked reduction in fishing intensity on the second opening day, the CPUE did not significantly increase in April 2006, most likely a result of the poor weather conditions; strong winds and large waves reduced the available gleaning area, so that groups of fishermen were unable to fish to their full potential.

Management Implications

This study supports the growing evidence that marine reserves can benefit fisheries (Hawkins, Roberts, Dytham, Schelten & Nugues 2006; Polunin & Roberts 1993; Watson & Ormond 1994). NTZs are used to manage fish stocks because of their potential in the recovery of depleted stocks, prevention of recruitment overfishing and spillover of stock to adjacent fished areas. Cephalopod fisheries are becoming the subject of an increasing number of management interventions as overexploitation becomes a greater problem (Defeo & Castilla 1998; Hernández-García *et al.* 1998; Lynch, Hooper, Blais, Meunier, Perrine & Ravanne 2003; Worms 1983), especially in the western Indian Ocean (Lynch *et al.* 2003). Recommendations for the management of cephalopod fisheries have focused on reducing the fishing effort instead of limiting the quantity fished (Basson *et al.* 1996; Caddy 1983; FAO 2005), partly due to the fact that stock forecasting with short-lived species, such as octopus, is entirely dependent on recruitment, which is highly unpredictable (Boyle 1990). The response of octopus to protection has had mixed results in the past (Defeo & Castilla 1998; Halpern 2003; Pipitone *et al.* 2000) but this study shows clear responses in the octopus fishery to closed fishing periods.

Whilst Roberts *et al.* (2003) propose the benefits of fully protected reserves this was not a feasible management option in an area where no marine resource management had occurred previously. The first closure of the NTZ was a trial conceived and supported by the local community and no agreement would be reached regarding further management suggestions until the benefits from this first NTZ had been seen. Marine resource management is likely to be more successful if the local community and stakeholders are directly involved in the decision making processes (Billé & Mermet 2002a), a major factor in the success in the implementation and respect of the Nosy Fasy NTZ.

Whilst both closures resulted in similar increases in the mean weight of octopus, the first, 7 month closure produced a much greater abundance of octopus compared to the second 4.5 month closure. Anecdotal reports from the second opening day suggest that fishers were expecting greater catches and that June was considered a more appropriate time to reopen the NTZ. The closed periods were timed to coincide with not only the brooding season of *O. cyanea* (G.) (Laroche, pers. comm.), but also with the low octopus fishing season, because heavy rain prevents octopus collection vehicles reaching the region, and the warmer waters during this season increase the catch of finfish in the region.

The results from the closures of two replica NTZs in the region between December 2005 and April 2006 will provide further information on the suitability of NTZs as a management tool in the region. These will be available in a second report.

Limitations

The B.A.C.I. (Before After Control Impact) design of this study is a powerful tool to test for the effects of the NTZ, and coupled with the use of multiple control fishing sites has overcome many of the problems associated with interpreting the results of a reserve correctly (Willis 2003; Underwood 1992). The multiple control sites eliminate the variation in octopus landings as a result of annual deviations (García-Rodríguez, Fernández & Esteban 2006; Silva *et al.* 2002) and environmental fluctuations (Boyle & Boletzky 1996; Rodhouse 2001). Ideally there would have been a greater number of pre-closure surveys from Nosy Fasy and the control sites but after it was agreed to create an octopus NTZ in September 2004, it was not only important that the impetus behind the management decision was maintained but that the NTZ was closed at the start of the main brooding period for *O. cyanea* (G.) in SW Madagascar, since reducing fishing effort over the brooding period could have increased the effectiveness of the NTZ.

The deficiency in information on fisheries in Madagascar has been a factor limiting the monitoring and management of the octopus fishery nationally. However, gathering fisheries data from different sources by an independent body, as has been pioneered in this study, provides an accurate means of raising awareness of the status of the fishery amongst relevant stakeholders, in order to improve management decision making.

The continual monitoring of the octopus fishery in the Andavadoaka region is a large task and one that requires a large amount of funding. For this reason, the current scope of this project has been limited to the Andavadoaka region, close to the Blue Ventures research site where Malagasy and international scientists have been able to work closely and communicate effectively with the local population. The future expansion of this project is limited by the difficulty in accessing villages at greater distances in order to relay the results from the Andavadoaka NTZs and in collecting fisheries data from further afield.

The current collaboration between Blue Ventures and private-sector companies, those with a stake in the octopus fishery of the region, has also been essential in the success of the NTZs. The partnership developed between Blue Ventures and Copefrito, a first in Madagascar, has already led to discussions of an increase in the amount paid per kg for larger octopus. It is vital that these channels of communication and mutual understanding remain open if the benefits of the NTZs are to be enjoyed by both the local fishers and fishing companies, and to promote sustainable fisheries management regionally.

Summary

Artisanal fishing for octopus is a vastly important economic and subsistence activity for the Vezo communities of SW Madagascar. Copefrito has doubled the volume of marine products brought in the region between 2003 and 2005, totalling 1 000 000 000 MGA, of which 88 to 92% is paid to the fishers, with octopus representing 60 to 70% of the total products brought. As the fishing population increases, along with commercial interest in the fishery, it is particularly susceptible to overexploitation (Cherif 2001; Laroche 1997). Increasing foreign demand (FAO 2005) encourages rising catches without a corresponding increase in scientific information or management practices (Cortez *et al.* 1999; Defeo & Castilla 1998) and a lack of data prevents reliable estimates of fisheries resources in Madagascar (Billé & Mermet 2002b). Increases in octopus fishing in between the spring tides have been reported (Langley 2006), decreasing the periods of traditional reductions in fishing pressure. Although the Malagasy Ministry of Fisheries has estimated that fisheries resources are currently under or optimally exploited, evidence from research and interviews with traditional fishers report diminishing catches for many marine resources (Iida 2005; McVean *et al.* 2005; Rakotonirina & Cooke 1994; Woods-Ballard *et al.* 2003). The early introduction of management schemes is advised in areas where an artisanal fishery expands rapidly as commercial interest grows, in order to reduce future potential socioeconomic impacts (Defeo & Castilla 1998; Jennings & Polunin 1996; Silva *et al.* 2002).

The results of the first seasonal closures of an octopus NTZ in south west Madagascar have shown that short-term closures of a reef flat to octopus fishing can lead to an increase in the number of octopus fished once reopened. Most importantly, the mean weight of octopus caught increased by an average of 48% after each closure period coupled with an increasing shift in weight distribution, so that there was a 32% increase in the number of octopus caught over 500g from September 2004 to June 2006. The increase in mean weight means that fishers, who are paid by the kg of wet weight of octopus, will have increased their earnings. Increasing the average size of the octopus population should also increase its reproductive output.

Decreasing the fishing intensity on the opening day could increase the length of the benefits of the NTZ, but the potential economic benefits of fishing the opening day, along with cultural ceremonies associated with each opening prevent restricting the fishing effort on opening days.

Finally, the future management of the octopus fishery must take into account the importance of choosing the correct time and length of closure of NTZs in order for the maximum benefits to be gained by the local fishers in order to maintain their continued support in the NTZs.

Acknowledgements

Blue Ventures would like to thank Drs. Edouard Mara and Man Wai Rabanenavana of the University of Toliara's IHSM as well as Simon Harding and colleagues at the Wildlife Conservation Society in Antananarivo, and all staff at Copefrito who have assisted with this research. The authors also thank the people of Andavadoaka, without whose time and support this research would not have taken place. Particular thanks also go to Victor Bonito, Katie Yewdall, Thomas, Bic Manahira, Loic l'Haridon, Alex Mason, Minna Epps, Josephine Langley, David Griffiths, Emma Doherty, Amelia Curd, Tom Hardy and Richard Nimmo of Blue Ventures. Blue Ventures would also like to thank all the staff and research volunteers that have worked in Andavadoaka since 2003.

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